

On Sinhalese Iron and Steel of Ancient Origin.

By Sir ROBERT HADFIELD, F.R.S.

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[PLATES 2—5.]

Introduction.

The use of iron has without doubt existed from a time dating back to a very early period in the world's recorded history. Owing, however, to the avidity of the oxygen present in the air for this metal, it has been most difficult to obtain *ancient* specimens of iron. We have therefore but little definite evidence regarding its early manufacture and use. It is for this reason the author thought that the present description of some interesting Sinhalese specimens of this nature which came under his notice during a recent tour in the East would be of interest to the Royal Society.

This is not the first time that the Royal Society has had presented to it papers on the subject. One hundred and sixteen years ago—to be exact, on June 11, 1795—Dr. George Pearson, a Fellow of the Royal Society, read a paper entitled “Experiments and Observations to Investigate the Nature of a Kind of Steel, Manufactured at Bombay, and there called Wootz, with Remarks on the Properties and Composition of the Different States of Iron.”

It was the author's good fortune to visit the Colombo Museum and there see a large number of ancient specimens of iron and steel obtained from some of the buried cities of Ceylon, so well known to archæologists. These cities date from about 500 B.C. and had a continuous history up to about 1500 A.D.

Through the kindness of the Governor-General of Ceylon, Sir Henry McCallum, to whom grateful acknowledgment is here made, the author was accorded the privilege of having placed at his disposal a few of these interesting specimens for investigation. It is believed that the research which has now been carried out yields information not previously available on the subject of iron and steel specimens of known ancient origin; in fact, no previous publications appear to present any complete and authentic analyses accompanied by mechanical tests and photomicrographs showing the structure of such material.

Not only does the Colombo Museum contain this large number of interesting specimens of ancient tools and implements of various kinds, some 250 in number, but in another section of its exhibits are shown several swords of more modern date, bearing upon them the dates of the years 1374 and 1416 A.D., with Sinhalese legends inscribed upon them. To those interested

in the metallurgy of iron and steel this collection makes special appeal as being the most complete and unique yet known.

The following is the description of the specimens sent to the author for the purpose of this research :—

1. Museum No. 138. Steel chisel from Sigiriya, of the fifth century (A.D.). Length, 10 inches.
2. Museum specimen, unnumbered. Ancient nail (pointed end broken off), $13\frac{1}{2}$ inches long, probably also from Sigiriya, of the same date as the chisel, but the particulars are lost. It is, however, certainly very ancient and is typical of a certain class of implements found in the ruined cities of Ceylon.
3. Native billhook or “ketta,” just as it came to hand from Dumbara, near Kandy, the headquarters of much mediæval native work.

In a fuller paper on this subject, given elsewhere, the author deals with (Section B) opinions of various authorities with regard to the so-called Iron and Bronze Ages; (Section C) remarks on the paper communicated in the year 1795 by Dr. Pearson, F.R.S., to the Royal Society, on Indian Wootz steel; (Section D) Heath and others on Indian and Sinhalese iron and steel; (Section E) Delhi and Dhar pillars in India; (Section F) remarks by MM. Osmond and Maspéro.

The present paper contains only the section dealing with the physical and chemical characters of the metal of the above specimens, and only a selection of the numerous photographic illustrations prepared.

A brief reference may be made to the interesting question of the hardness retentivity of ancient specimens of iron and steel. This subject has also been dealt with by Dr. Cecil H. Desch in his recent interesting work on “Metallography.”

Dr. Desch speaks of the phases retained by quenching being commonly spoken of as metastable. He considered, however, that whilst experimental proof had not been produced, we were bound to assume that the metastable limit had been passed, and that the systems are correctly described as labile, not as metastable. Quenched specimens, therefore, tend spontaneously to assume an equilibrium condition by undergoing the transformation which was suppressed by quenching. It is uncertain how far the spontaneous change can proceed at ordinary temperatures. White tin, which is only stable above 18° , does not change into grey tin at 0° unless brought into contact with the new phase. Below 0° the change can occur spontaneously, although even at low temperatures it may fail to occur when the tin is kept for long periods. This would seem to indicate that the metastable limit for tin lies much below 0° .

Dr. Desch considers that hardened steel is undoubtedly labile at the ordinary temperature, and the presence of the stable phase is not necessary

to initiate change. But there is little evidence that softening of steel takes place spontaneously unless the temperature is raised. He also states that Japanese swords of the XVth Century, when carefully preserved, are found to be as hard at the edge as if newly hardened; it would therefore seem that no appreciable return to the stable takes place in the course of several centuries at atmospheric temperatures. On the other hand, prolonged heating of hardened steel even at 100° produces an appreciable softening, and heating at 150° in a few minutes. The whole question of labile and metastable conditions in undercooled solid alloys demands fuller investigation.

The above statement by Dr. Desch is particularly interesting in regard to the present paper, because it shows that hardened material of ancient origin, when found in soft condition, may really have originally been quite hard. Thus, the edge of the ancient chisel, described in Experiment No. 2252, distinctly shows a defined structure in certain parts, differing from the other portion, apparently martensitic, as if it had once been in the hardened condition, but, by the expiration of time, had gradually assumed the condition in which it was now found, that is soft. On the other hand, this particular chisel may not have been hardened, although the micro-structure, by the presence of troostite, seems to indicate that this may have once been the case.

Description of the Present Research Experiments.

Details of the various specimens, and an account of the research conducted, with the results achieved, may now be given, these experiments being carried out by the author at the Hecla Works Laboratory and Research Department.

Experiment No. 2252.—This was carried out upon the ancient Sinhalese chisel, being specimen marked No. 1 by Dr. Willey, and shown in fig. 14 (1), Plate 2. This dates back to the Vth Century. The specimen was very rough but without scale, and had an undulating surface, possibly due to unequal corrosion, and it is possible that the material was forged with rough implements of stone. The chisel was about 10 inches in length, and at the upper portion, away from the edge, about $1\frac{3}{16}$ inches square, $\frac{1}{16}$ inch by $\frac{3}{16}$ inch in the centre, tapering to a point as with modern tools.

Table I.—Composition.

C.	Si.	S.	P.	Mn.	Fe.	Specific gravity.
traces	0.12	0.003	0.28	nil	99.3	7.69

The difference represents slag and oxide.

Tensile Strength.—The Fremont shear test showed 16 tons per square inch elastic limit, 26 tons per square inch breaking load.

Shock Test.—The shock test, on un-nicked specimen, showed 17 kgrm. with 85° bend before breaking.

Hardness.—The Brinell ball test showed hardness numbers of 144 and 144 on the opposite side of the chisel. The scleroscope hardness number was 35.

The fracture was unsound, apparently owing to the existence of unsoundness or blowholes. The crystalline structure showed large sparkling crystals. The micro-structure of the specimens, shown by the photo-micrographs numbered fig. 15 (Photo 318, transverse section) and fig. 16 (Photo 318A, longitudinal section), brings out several points of interest. The transverse section shows that this chisel has been carbonised, the section showing the carbonised areas to be on two sides. The carbonisation varies on the two faces from saturation point (0·9 per cent. carbon) to about 0·2 per cent. carbon on the outside edge, and the depth of the carbonisation from the edge inwards is also shown to be variable. The presence of martensite and hardenite (fig. 15, Photo 318, carbonised area) suggests the important fact that the chisel has been quenched.

Some of the crystals give evidence of a structure probably due to impurities of phosphorus and sulphur. The longitudinal photographs of both the chisel and the nail show this structure. A further micro-section was prepared from the specimen cut from the nose of the ancient chisel. This photo-micrograph (not here reproduced) carries evidence, in the author's view, that it has been quenched, for the structure is in parts martensitic. Troostite is certainly also present, which is probably the result of tempering by the long lapse of time.

The author believes this is the first time there has been put on record evidence that the art of cementation must have been known 1500 to 2000 years ago, as shown by these specimens; probably, therefore, such knowledge would go back still further.

Experiment No. 2253.—This was carried out upon the ancient Sinhalese nail, specimen marked No. 2 by Dr. Willey, the Director of the Colombo Museum, and is shown specimen No. 2 (Plate 2, fig. 14, Photo 1471). This is probably of the same origin and age as the chisel just described. This nail is about 13½ inches in length, and $\frac{5}{8}$ inch by $\frac{9}{16}$ inch at the point; the extreme point is missing.

Table II.—Composition.

C.	Si.	S.	P.	Mn.	Specific gravity.
traces	0·11	nil	0·32	nil	7·69

Tensile Strength.—The Fremont shear test showed 11 tons per square inch elastic limit, 21 tons per square inch breaking load.

Shock Test.—The shock test, on un-nicked specimen, 0·5 kgrm. by 1°, that is, it was very brittle.

Hardness.—The Brinell ball test showed hardness numbers of 117 and 209 on opposite sides of the nail. The scleroscope hardness number was 44. The fracture revealed a fine bright crystalline structure.

The micro-structure (see Plate 4, fig. 18, Photo 317A, and fig. 19, Photo 317B) indicates a remarkable conglomeration. Fig. 19 shows a weld running diagonally across the section, and along the edges of the weld there are carbonised areas. Another notable point is that on one side of the weld the slag shows the effect of the forging, whereas on the other side there is no such sign. The specimen is covered with slip bands, and has evidently undergone severe hammering, probably in its use as a nail. The carbon in the carbonised areas exists as granular pearlite; Photo 317 (not reproduced) is a transverse section, and figs. 18 and 19 are longitudinal sections, but of different fields.

The longitudinal photographs of both the chisel and the nail, figs. 16, 18, and 19, show evidence of a structure.

The fragment from the nail was heated and forged well up to about 1150° C. As forged, the Brinell ball hardness number was 120. The same material heated to 1050° C. and quenched in water showed 130 Brinell ball hardness number, showing that it was not hardened by quenching.

Experiment No. 2254.—This was carried out upon the ancient Sinhalese billhook, specimen marked No. 3 by Dr. Willey, and shown in fig. 14 (3) (Photo 1471) on Plate 2. The specimen was very rusty, being covered with a thick brown rust. The billhook is about 12½ inches in length, 3½ inches in width at the blade, the handle being 4½ inches in length.

Table III.—Composition.

C.	Si.	S.	P.	Mn.	Specific gravity.
traces	0·26	0·022	0·34	traces	7·50

Tensile Strength.—The Fremont shear test showed 16 tons per square inch elastic limit, 29 tons per square inch breaking load.

Shock Test.—The shock test on un-nicked specimen gave 7·1 kgrm. by 35° bend only.

Hardness.—The Brinell ball test showed hardness numbers of 153 and 166 on opposite sides of the billhook. The scleroscope hardness gave number 23. The fracture showed bright crystalline structure, laminated appearance.

The report on the micro-structure of the specimen, as shown by photo-

micrographs, figs. 20 (Photo 319) and 21 (Photo 319A) on Plate 5, is that the specimen contains a large amount of slag, and appears to represent what would be now termed a somewhat low quality of wrought iron. There seems to be practically no carbon present, and therefore no evidence of treatment other than forging can be obtained. Fig. 20 is the transverse section and fig. 21 the longitudinal section.

Special interest attaches to the analyses given, as they probably represent the only modern complete and accurate determination of the composition of known and authentic specimens of ancient iron.

The percentage of phosphorus is, it will be noted, high, from 0.28 up to 0.34 per cent., which, however, does not greatly differ from modern bar iron. The sulphur percentage is extremely low, showing that a very pure fuel, no doubt charcoal, was employed in the production of the material. There is very little silicon present and manganese is entirely absent, which is somewhat remarkable, as nearly all iron contains some manganese.

As the specimens from which to produce ordinary tensile pieces were too small, tests were obtained by means of the ingenious Fremont shear-test method. The tensile quality of the material averages about 26 tons per square inch, or a little higher than wrought iron. This, no doubt, is owing to the considerable percentage of phosphorus present, which stiffens or hardens iron. The Fremont shock tests show fair results on the specimen taken from the chisel, namely, 17 kgrm. with 85° bend. The other specimens, however, show much lower figures, namely, the nail, 1 kgrm. by only 1° bend, and the billhook 7 kgrm. by 35° bend. The hardness by the Brinell method varied from 117 to 166, one result from the nail showing 209, but this is abnormal and cannot be accepted as representative. The scleroscope tests varied from 25 to 44, and as a comparison it may be mentioned that dead hard steel, by this latter method, shows 100, and ordinary wrought iron about 20.

From the microscopical examination, and from the other tests carried out, the specimens represent a material of the type known as wrought iron, and not steel. The specimens somewhat resemble the material known as puddled iron, and appear to have been made from somewhat impure ore. The material is very low in its percentage of carbon, and, excepting phosphorus, also other impurities. There is present, in a lumpy irregular form, quite a large amount of slag, indicating that the material has not been submitted to anything like the amount of squeezing and forging that the modern wrought iron undergoes.

DESCRIPTION OF PLATES.

PLATE 2 (fig. 14).

- (1) Ancient chisel from Sigiriya, 5th century (A.D.). Two-thirds actual size.
- (2) Ancient nail, from Sigiriya, 5th century (A.D.). Two-thirds actual size.
- (3) Ancient "ketta" or billhook. Two-thirds actual size.

PLATE 3 (figs. 15, 16).

Transverse and longitudinal sections of chisel, as marked. Magnification 80.

PLATE 4 (figs. 18, 19).

Transverse and longitudinal sections of nail, the longitudinal showing weld. Magnification 80.

PLATE 5 (figs. 20, 21).

Transverse and longitudinal sections of billhook. Magnification 80.

Note on the Monatomicity of Neon, Krypton, and Xenon.

By Sir WILLIAM RAMSAY, K.C.B., F.R.S.

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The monatomicity of neon, krypton, and xenon has been taken for granted on somewhat insufficient evidence. When the memoir on Argon and its companions* was written it was stated that no experiments with the pure gases had been carried out on the ratio between the specific heat at constant volume and constant pressure, but that measurements made with impure samples indicated the ratio 1.67; and it was remarked that such a ratio could not have been found had any considerable portion of the mixture consisted of a polyatomic gas.

Having now at my disposal relatively large quantities of pure neon, which had served Mr. Watson, and of pure krypton and pure xenon, which had served Prof. Moore, for determining the densities of these gases, it appeared advisable to fill the gaps in our knowledge of their specific heat ratios.

The apparatus was similar to the one described in the memoir on Argon†; the wave-length of sound in neon was compared by Kundt's method with that in air; and the krypton and xenon, previously frozen and purified by pumping them free of any possible content of air, were also investigated in the same manner.

* 'Phil. Trans.,' A, 1901, vol. 197, pp. 82 and 83.

† 'Phil. Trans.,' A, 1895, vol. 186, Part I, p. 228.